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EVALUATION OF THE CAST SYSTEM DURING THREE YEARS OF OPERATION

By

P. Scott Hill and Tim Gerrodette

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ABSTRACT

The Computer Assisted Sighting Technology (CAST) system was developed to improve the accuracy in angle and distance measurements taken during shipboard cetacean surveys. Three years of data collected by the CAST system were evaluated. Most differences between CAST and observer angles were small; however, there was a significant number of large discrepancies which could not be accounted for. No comparison of distances was possible because the CAST system provided so few estimates of distance. Only five good distance estimates were realized for the 1043 dolphin schools encountered over the three year period. Probable reasons for the failure of the CAST system to perform as expected were changes in speed and direction by the dolphin school, and difficulties in maintaining continuous visual tracking of the dolphin school.

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INTRODUCTION

The yellowfin tuna (Thunnus albacares) purse-seine fishery in the eastern tropical Pacific results in the death of thousands of dolphins (Stenella spp. and Delphinus delphis) each year (DeMaster et al. 1991; IATTC 1992). Under the Marine Mammal Protection Act, the National Marine Fisheries Service has the responsibility of monitoring and assessing the status of these dolphin populations. To this end, estimates of tropical dolphin abundance are made based on large-scale surveys from NOAA research ships (Holt and Sexton 1989a; Wade and Gerrodette in press).

Line-transect analysis (Burnham et al. 1980; Buckland et al. in press) requires measurement of the perpendicular distance to each sighted object. For objects such as dolphins that can move, the perpendicular distance is computed in practice from two measurements taken when the dolphins are first seen: the radial distance (r) to the school and the angle (θ) of the school from the ship's trackline. The perpendicular distance (d) is computed from the trigonometric identity $d = r \sin \theta$. In our surveys, angles (θ) were read from a radial scale mounted on the binocular pedestal, and radial distances (r) were estimated from a calibrated reticle in the binocular eyepiece. Both data were recorded for each marine mammal sighting on a regular data form.

Errors in measuring either r or θ can lead to a positive bias in the estimation of abundance (Butterworth 1982). The Computer Assisted Sighting Technology (CAST) system was developed to improve the accuracy in angle and radial distance measurements. The CAST system was developed at the Southwest Fisheries Science Center through various contracts between 1981 and 1987. CAST had both hardware and software components¹. The hardware consisted of a pitch-and-roll sensor, a shaft encoder and data pad on the binocular pedestal, connections to the ship's gyrocompass and speed log, and a microcomputer to process the information. The distance to the sighted object was calculated by triangulation using bearings-only target motion analysis (Nardone and Aidala 1981; Petridis 1981). Successive angle measurements (adjusted for the movement of the vessel) and distance travelled by the ship (calculated from course and speed) were processed through a Kalman filter (Aidala and Hammel 1983). While the system is capable of

¹ Adamo, L.C. 1984. CAST system hardware and software documentation. Solana Beach, CA, USA. 11 pp. (unpublished).

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(calculated from course and speed) were processed through a Kalman filter (Aidala and Hammel 1983). While the system is capable of performing the analysis in real time, we did not use CAST in this way. We followed a defined tracking protocol (described below) and recorded all data in computer files. Data were analyzed after the cruises with the post-cruise processing program POST written for that purpose.

FIELD PROCEDURES

The CAST system was installed aboard two NOAA research vessels, McARTHUR and DAVID STARR JORDAN. Data from the CAST system were gathered during four Monitoring of Porpoise Stocks (MOPS) surveys, 1986 through 1989 (Holt and Sexton, 1987, 1988, 1989a, 1989c; Holt and Jackson, 1987, 1988; Sexton et al. 1989; Hill et al. 1990a, 1990b). Records here are combined for both ships.

On the flying bridge of each vessel, two pedestal-mounted 25x150 Fujinon binoculars were utilized to search for marine mammals. Not all marine mammals sighted were tracked with the system. Tracks were attempted on dolphin schools containing more than 15 animals encountered within 5.6 km lateral to the vessel that were detected during good sighting conditions. All whales and those dolphin schools encountered too close to the vessel were not tracked.

At the time the marine mammal observer sighted a cue, the angle and distance to the cue were recorded. The angle was read from a 360° graduated washer attached to the base of the 25X binoculars and recorded on the Research Ship Marine Mammal Sighting Record (hereafter, Sighting Record). Ideally, tracking should have begun immediately afterward and the sighting time and angle recorded by CAST should have been the same as the time and angle recorded manually by the observer in the Sighting Record.

The observer initiated a CAST tracking sequence by turning on a switch attached to the binocular stand. Shaft encoders installed within the binocular mounts electronically encoded angle measurements at a rate of 4 per second. Software running on a microcomputer interpreted angle data and corrected for the movement of the vessel via inputs from the ship's gyroscope, speed log, and a pitch-and-roll sensor. Angles were processed through a Kalman filter at 6 second intervals (smoothed over a sample size of 24) to account for random tracking noise. When the dolphin school was not in the field of view, the switch was turned off until the school was again sighted. The tracking procedure was terminated if the school was lost from view and not resighted.

In order to achieve reliable data from CAST, it was necessary to follow a specific tracking strategy. The first leg, or first portion of the track, began at the time of the initial sighting when the tracking switch was first turned on. If the initial relative bearing to the target was greater than 20 degrees, the

vessel maintained a constant course and speed for 8 minutes. For targets with smaller initial relative bearings, the duration of the first leg was extended until the relative bearing to the target had changed by 10 degrees. For targets that were close in, the first leg could have been shortened if the bearing to the target had changed by 20 degrees or more. Once the first leg was completed, the vessel initiated a course change to intercept the target. The second leg began when the ship had steadied up after the course change. The duration of the second leg was either 8 minutes, when the target had been intercepted, or when the target passed abeam, whichever occurred first. These tracking rules were based on the design of the algorithm used in the CAST software and were explicitly laid out in the CAST User Manual².

A report on the CAST Target Tracking Simulation Analysis was completed by Hopkins and Associates³. The report explored the effects of error sources and tracking perturbations on the performance of the CAST tracking algorithm. The analysis demonstrated that reliable distance estimates could be obtained by a target on constant course and speed that was tracked using the two-leg intercept method. The CAST system performed satisfactorily even with poor or noisy angle tracking, periods of missed tracking, or poor selection of own-ship course (the course chosen to intercept the school) for the second tracking leg.

In addition, the simulations showed that it was crucial for the target (the dolphin school) to maintain a constant course and speed throughout the tracking sequence. The "CAST tracking algorithm _____ very sensitive to any kind of maneuver by a target during any part of the tracking engagement³." The ability of the observer to track the original target was also shown to be critical for the CAST tracking algorithm to estimate distance properly.

Because the CAST system was not in its final working form during the 1986 cruises, data collected that year were not utilized in this study. Only the data collected during the 1987, 1988, and 1989 cruises are included in this analysis.

This report analyzes both components of the data collected by the CAST system (angles and radial distances). First, we compare the initial angle recorded at the time of the sighting ("observer angle") to the angle at the beginning of the CAST track ("CAST angle"). We also compare the times at which the angles were

² Hopkins, R.D. 1986. CAST marine mammal survey system user manual. Hopkins and Associates, Solana Beach, CA USA. 12pp. (unpublished)

³ Hopkins, R.D. 1987. CAST marine mammal survey system target tracking simulation analysis. Hopkins and Associates Solana Beach, CA, USA. pp. 76 (unpublished).

recorded. Next, we take a subset of all tracks collected and analyze them with the post-processing program (referred herein as POST) in order to assess how well the CAST algorithm estimated the initial range (the radial distance) to the sighted school.

ANALYSIS

Angles

For the angle analysis, we examined all CAST tracks obtained over the period from 1987 through 1989. We matched each CAST track to the original sighting record by date, time, and sighting number. This was necessary because at times the sighting number was either entered wrong or not entered into the CAST system. There were also a number of CAST tracks in which no sightings were actually made (i.e., the system was accidentally switched on when no sighting had occurred).

The initial angle of the CAST system was taken as the difference between the first data record of a particular track and the gyrocompass reading (the ship's direction). It was necessary to add 360° to this value when it was negative to make it comparable to the initial angle as recorded by the observer. For each track we compared the initial angle from CAST to the initial angle recorded manually by the observer on the Sighting Record. Histograms were constructed for the difference between CAST angle and observer angle within each of the three years (Figures 1-3).

In order for the angle comparison to be meaningful, the times at which angles were recorded by CAST and recorded manually on the Sighting Record should be very close. However, the time and angle recorded on the Sighting Records were taken when the cue was sighted. The time of the sighting cue was, therefore, not necessarily the same time the CAST track was initiated. For instance, if splashes (the sighting cue) were seen on the horizon, then that time and angle were noted on the Sighting Record. The animals might not have been detected and thus the CAST track not initiated until a full twenty minutes after the cue was first sighted. In this instance, the initial times and, hence, angles of the cue and CAST track could be very different.

When a CAST track was initiated, the time (which we will refer to as CAST time) was noted in a header proceeding the data. If the first data record contained data, the CAST time used was that occurring in the header. If the first data record or group of data records was empty, then the difference between the time in the header and the time associated with the first full data record was taken into account. We compared the CAST time with the observer time, the time of the sighting (actually the cue) taken from the Sighting Record. Some rounding error was introduced because the observer time recorded on the Sighting Record was only to the nearest minute whereas the CAST time was recorded to the nearest second. For each sighting we subtracted the observer time from the

CAST time in order to obtain the time difference for each sighting. Histograms were then constructed for time difference comparisons for each of the three years (Figures 4-6).

For each of the three years we also constructed scatterplots of time difference versus angle difference in order to examine correlation between those variables (Figures 7-9).

Distances

For the distance analysis, because there were hundreds of CAST tracks for each year (584 tracks in 1987 alone), we decided to look at a subset of the data. We analyzed tracks only for dolphin schools that were used each year in the abundance estimates (Holt and Sexton 1989b; Holt and Sexton 1990; Gerrodette and Wade 1992). These included all dolphin schools with 15 animals or more, sighted in a Beaufort state less than or equal to 5, and within a 3.7 km perpendicular distance from the trackline (as calculated by the observer estimates of angle and distance). We obtained a list of all dolphin sightings used in the abundance estimates for each of the years and matched the sightings on this list to the actual CAST tracks.

The initial radial distance to the dolphin school was calculated from the CAST data by the POST program written by Hopkins and Associates in 1986. POST requires the user to make a number of decisions about how to analyze the tracking data. Many times after a school was sighted and the track was initiated, the school was lost. A switch on the binocular stand inhibited the system from collecting information during such periods. The tracking sequence, however, was not terminated until the observer terminated the track using a function on the keypad. This enabled the observer to resight the school and resume the same tracking sequence. During these times, empty data records were collected. Therefore, it was necessary to run the POST program for all tracks in order to see how much of each track contained empty data records.

For the present analysis it was necessary to determine how many full data records (records containing data) the algorithm needed in order to have even a remote chance at converging on an initial range (radial distance). After running POST on an assortment of tracks, we decided to set a lower limit of thirty (30) as the minimum number of full records needed by the algorithm. This estimate is conservative because most tracks with 80-90 full records did not converge on an initial distance. The algorithm apparently requires more data. Ninety data records equates to only 9 minutes of tracking (a data record is logged each six seconds) and the developer of the CAST system suggested two eight-minute tracking legs with good geometry in order to obtain valid estimates based on simulated trackings².

Each track containing thirty or more full data records was

processed using the POST program. During the POST processing, the vessel speed displayed in the header of the track was checked. If the value was unreasonable, the value was changed to the speed shown on the Research Ship Marine Mammal Daily Effort Log at the time the track was made. The vessel speed was changed only if we were sure the speed computed by the speed log (and input into the CAST header) was in error.

The track was then processed for a first time. The output from the program was analyzed and certain changes could be made before additional processing runs were completed. Bad blocks of data could be taken out of the processing sequence, or the processing could be restricted to certain portions of the data set. Slightly increasing the value of RMS (root mean square) Angle Noise would give the program a better chance at converging because it would make the algorithm less sensitive to the angle noise.

We looked mainly at how ESTERR and BRGRTE changed throughout the tracking sequence in order to discover bad data blocks. ESTERR is the estimated error in the angle measured by the binoculars. This number in theory shows angle tracking noise, or how well the algorithm is tracking. As the algorithm is analyzing the incoming angles it figures out the rate at which the angle is changing. Departures from how CAST "sees" the school moving and how the observer follows the school moving are measured by ESTERR. The closer this value is to zero, the more likely the assumptions of the algorithm were being met.

BRGRTE displays bearing rate (i.e., the rate at which the target's bearing is changing, measured in degrees per minute). With the vessel maintaining course and speed it is possible to get a good idea of what the school is doing. If the bearing rate begins to increase (increasing or the angle opening to the right) and then turns highly negative (decreasing or opening to the left), then it may indicate the school is maneuvering. At times BRGRTE would exhibit an increase, decrease, increase, decrease type pattern which we refer to as zigzagging.

Tracks were processed up to a dozen times before the final processing decisions were made. Tracks were placed into three categories; GOOD, FAIR, and BAD. Tracks in which the algorithm converged on a reasonable estimate of radial distance and had fairly low final statistic values, MEAN VALUES (DEG) and RMS VALUES (DEG), were considered GOOD. The distance had to be reasonable because some tracks had low statistic values, but converged to distances well past the horizon.

Tracks were considered FAIR when the algorithm nearly converged at a reasonable distance while the statistics remained at fairly consistent values throughout the track (displaying that the algorithm was able to make some sense of the data). Small amounts of target transfer, slight school maneuvers, poor angle geometry,

or not quite enough data were thought to keep the algorithm from converging.

Tracks were deemed BAD if the algorithm could not make sense of the data causing the statistics to become chaotic, if the vessel never attempted a second leg, if there were simply insufficient data for the algorithm to converge, or if the estimated distance was negative or beyond the horizon.

We attempted to determine the cause of BAD tracks. While following the statistics during processing of the tracks with the POST program, it was usually possible to make a best guess at why the algorithm did not converge on a solution. It was easier to tease out why the algorithm did not work in BAD tracks than in FAIR tracks, though not straightforward. We kept a tally of why we felt each BAD track did not converge.

With the vessel maintaining course and speed, we considered changes in the direction of the bearing rate (BRGRTE) or major changes in BRGRTE as dolphin school maneuvers. We considered large, immediate changes in the relative bearing to the target as target transfer. Tracks in which no second leg was attempted or there was not enough data for the algorithm to converge were considered to have insufficient data in the second leg. Tracks in which the target's relative bearing did not change significantly during the first leg and not enough data were collected for the algorithm to converge were considered to have demonstrated poor angle geometry. Tracks that did not converge and had either a very short first leg or a majority of empty records in the first leg were considered to have insufficient data in the first leg. Operator error occurred when the relative bearing to the target seemed to jump around as if the operator was scanning to either look at or find the school instead of tracking it.

We note that the reasons for not obtaining a unique solution for the estimate of distance from the tracks are not mutually exclusive. For instance, a track in which the school was lost and then resighted after a certain amount of time had elapsed would have a gap in the data (empty records). While empty records were being recorded, the CAST algorithm would continue to "track" the school using the last information obtained prior to losing the school. In many instances the tracks would not converge because the CAST algorithm expected the school to be in a different location than it actually was once it had been resighted. In this case, either the school could have performed a maneuver or a different part of the school was resighted (target transfer).

RESULTS

Angles

Observer angles and the CAST angles were usually within a few

degrees of each other (Figures 1-3). However, an uncomfortably large number of differences of more than 10 degrees occurred. This is a very large discrepancy. In most cases it was not possible to tell whether the outliers were due to the time difference, a glitch in the CAST system, or a misreading by the observer. In a few cases the CAST angle was clearly in error (e.g., behind the vessel). Assuming the influence of time difference was similar between years, there is one noticeable trend in the histograms. Proportionally more data points lie away from the center of the histogram, showing a greater difference between the CAST and observer angles from 1987 to 1989. It is impossible to know the cause for this difference, or even which angle is the correct one.

Several trends are noticeable when viewing the time difference histograms (Figures 4-6) for 1987 through 1989. During the period the sample size dropped over 40%, from 584 to 344. Note that this sample size is the total number of times CAST was utilized for a tracking sequence, not the number of completed tracks. In addition, the differences between CAST time and observer time increased from 1987 to 1989. Note here that a time difference with a negative value occurred when the CAST track was apparently started prior to the cue being sighted. This clearly indicated an inconsistency. It is not possible to start tracking an object before sighting it, but negative time differences as large as four minutes were recorded. The 1988 data (Figure 5) had the lowest proportion of negative time differences.

The scatterplots (Figures 7-9) indicate no apparent correlation between large time differences and large angle differences.

Distance

During the period from 1987 through 1989 a total of 1043 schools were utilized in determining the abundance estimates for eastern tropical Pacific dolphins (Table 1). A CAST tracking sequence was initiated for 65% (686) of these schools and 42% (435) had over 30 full data records. We processed these 435 schools with the POST program.

Of the tracks we processed, we labelled 88% (384) as BAD, 11% as FAIR, and only 1% as GOOD. We found only five tracks that converged to a reasonable distance with adequate precision. Therefore, CAST converged to a reasonable distance for roughly one half of one percent of all schools (5 out of 1043 schools) used in the abundance estimates.

Table 2 presents our best estimates of the probable cause of BAD tracks. Maneuvering of the school, target transfer, and insufficient data in the second leg of the track were the most common reasons why tracks were labelled as BAD. Table 2 contains errors stemming from the binocular operators, the team leaders (who initiated the ship maneuvers), and the dolphin schools. Recall

that the errors are not mutually exclusive, so more than one type of error may be present on a particular track.

DISCUSSION

The CAST system was developed to obtain improved angle and radial distance measurements for marine mammal surveys. To evaluate its performance, we attempted to compare CAST angles and distances during three years of operation with "manual" angles and distances made by the observers for the same marine mammal sightings.

The comparison of angles (Figures 1-3) showed that most differences between CAST and observer angles were not more than a few degrees. However, there were a significant number of large differences (>10 degrees). The comparison of times at which the angles were measured and, especially, the large number of times CAST tracking was apparently started before the dolphins were sighted (Figures 4-6) cast serious doubt on the value of CAST-observer angle comparisons because (1) CAST angles were not taken at the same time as the observer angle, and (2) CAST clocks and observer clocks were not synchronized. One would expect large time differences and large angle differences to be correlated; however, no correlation was apparent (Figures 7-9). This lack of correlation further indicates a large random component in the data. We conclude that the difference between CAST and observer angles tends to be small, and that it is not possible to determine which series of measurements is more accurate.

No comparison of distances was possible because the CAST system provided so few estimates of distance. Only five good estimates of distance were realized for the 1043 dolphin schools seen (Table 1). There are numerous reasons why the CAST system failed to perform adequately while at sea. Under good sighting conditions, there is no doubt that the percentage of good tracks would have been much higher. However, there are many potential sources of error. The operator must follow the same group of dolphins throughout the track, the geometry must be good, the vessel must conduct two complete tracking legs, and the dolphin school must not change its course and speed. All this must take place on a ship that is pitching and rolling in wide range of environmental conditions.

The most common reason for BAD tracks was a maneuver or multiple maneuvers of the dolphin school (Table 2). The CAST Target Tracking Simulation Analysis³ showed that the CAST tracking algorithm was very sensitive to any kind of maneuver by the target during a track. For a properly executed tracking sequence, the school must maintain a constant course and speed for at least a sixteen minute chase with a ship maneuver (maneuver conducted by the vessel during the track) in the direction of the school. Biologically, it is quite reasonable that the dolphins would change

speed and direction as the vessel approaches them. Because these dolphins are in areas where they have been encircled by tuna purse-seines, dolphins of the eastern tropical Pacific have become particularly wary of vessels (especially vessels which turn towards them). It is probable that dolphins violated the non-maneuver assumption of the CAST tracking algorithm during many of the tracking sequences.

Target transfer, the second most common reason for BAD tracks, occurred when the observer inadvertently shifted the binoculars from one part of the school to another. This type of error could be caused by the behavior of the dolphin school, poor tracking by the observer, or simply the motion of the vessel making it difficult to follow the same part of the school with the binoculars. As shown in the simulations, "there is nothing in the algorithm design to accommodate a shift to a different target³."

Insufficient data on leg two were also a common occurrence. A combination of human and dolphin reasons could have contributed to this type of error. If the dolphin school was lost or split into several subgroups the track would have been cut short. There are many reasons why the observer tracking the school would have cut the second leg short, including inability to keep track of the school, running into a squall, proximity of other vessels, and simply not letting eight minutes elapse.

The number of attempted tracks per year dropped by over 40% over the three year period. This points to the fact that the system was simply not being used as it had been designed. It is not possible to assess whether the drop in use was due to an earlier recognition of unsuitable schools for tracking, whether the scientific party simply became more familiar with the system and its limitations and would track schools only under superior conditions, or because the CAST system tended to break down more often during the final year of operation.

As a result of the poor performance of the CAST system during three years of operation, it was decided to discontinue its use. If a similar tracking system were to be developed in the future, it would have to overcome the two main problems that caused the failure of the CAST system: the system must be able to accommodate maneuvering by the marine mammal target, and the system must have a reliable way of tracking the marine mammal target as an idealized "point."

Table 1. Initial Range Analysis for CAST Data (1987-1989)

1043 total schools.....	100%
686 schools with an associated CAST track.....	65%
435 processed tracks (with over 30 records)...	42% (100%)
51 "FAIR" and "GOOD" tracks.....	5% (12%)
5 "GOOD" tracks.....	0.5% (1.1%)

Table 2. Probable Explanations for BAD CAST Tracks (1987-1989)

384 total number of "BAD" CAST tracks
196 maneuver of dolphin school
186 target transfer
158 insufficient data in leg 2 of track
58 poor geometry
48 insufficient data in leg 1 of track
9 operator error

LITERATURE CITED

- Aidala, V.J. and S.E. Hammel. 1983. Utilization of modified polar coordinates for bearings-only tracking. IEEE Trans. Automat. Contr. AC-28:283-294.
- Buckland, S.T., D.R. Anderson, K.P. Burnham, and J.L. Laake. 1992. Distance sampling: estimating abundance of biological populations, Chapman and Hall, London (in press).
- Burnham, K.P., D.R. Anderson, and J.L. Laake. 1980. Estimation of density from line transect sampling of biological populations. Wildlife Monographs 72:1-202.
- Butterworth, D.S. 1982. On the functional form used for $g(y)$ for minke whale sightings, and bias in its estimation due to measurement inaccuracies. Rep. Int. Whal. Commn. 32:883-888.
- DeMaster, D.P., E.F. Edwards, P.R. Wade and J.E. Sisson. 1991. Status of dolphin stocks in the eastern tropical Pacific. Wildlife 2001: Populations. D.R. McCullough and R.H. Barrett. Elsevier Press, London, England.
- Gerrodette, T. and P.R. Wade. 1992. Monitoring trends in dolphin abundance in the eastern tropical Pacific: Analysis of 1989 data. Rep. Int. Whal. Commn. 41: 511-515.
- Hill, P.S., A. Jackson, and T. Gerrodette. 1990a. Report of a marine mammal survey of eastern tropical Pacific aboard the research vessel David Starr Jordan July 29 - December 7, 1989. NOAA-TM-NMFS-SWFC-142. 143 pp.
- Hill, P.S., A. Jackson, and T. Gerrodette. 1990b. Report of a marine mammal survey of eastern tropical Pacific aboard the research vessel McArthur July 29 - December 7, 1989. NOAA-TM-NMFS-SWFC-143. 132 pp.
- Holt, R.S. and A. Jackson. 1987. Report of a marine mammal survey of eastern tropical Pacific aboard the research vessel McArthur July 29 - December 6, 1986. NOAA-TM-NMFS-SWFC-77. 161 pp.
- Holt, R.S. and A. Jackson. 1988. Report of a marine mammal survey of eastern tropical Pacific aboard the research vessel McArthur July 30 - December 10, 1987. NOAA-TM-NMFS-SWFC-116. 143 pp.
- Holt, R.S. and S.N. Sexton. 1987. Report of a marine mammal survey of eastern tropical Pacific aboard the research vessel David

- Starr Jordan July 29 - December 5, 1986. NOAA-TM-NMFS-SWFC-76. 171 pp.
- Holt, R.S. and S.N. Sexton. 1988. Report of a marine mammal survey of eastern tropical Pacific aboard the research vessel David Starr Jordan August 8 - December 10, 1987. NOAA-TM-NMFS-SWFC-117. 137 pp.
- Holt, R.S. and S.N. Sexton. 1989a. Monitoring trends in dolphin abundance in the eastern tropical Pacific using research vessels over a long sampling period: Analyses of 1986 data, the first year. Fishery Bulletin, U.S. 88:105-111.
- Holt, R.S. and S.N. Sexton. 1989b. Monitoring trends in dolphin abundance in the eastern tropical Pacific using research vessels over a long sampling period: Analyses of 1987 data. Rep. Int. Whal. Commn. 39:347-351.
- Holt, R.S. and S.N. Sexton. 1989c. Report of a marine mammal survey of eastern tropical Pacific aboard the research vessel David Starr Jordan July 28 - December 6, 1988. NOAA-TM-NMFS-SWFC-129. 129 pp.
- Holt, R.S. and S.N. Sexton. 1990. Monitoring trends in dolphin abundance in the eastern tropical Pacific using research vessels over a long sampling period: Analyses of 1988 data. Rep. Int. Whal. Commn. 40:471-476.
- Inter-American Tropical Tuna Commission. 1992. Annual Report - 1990. Scripps Institution of Oceanography, La Jolla, CA, USA.
- Nardone, S.C. and V.J. Aidala. 1981. Observability criteria for bearings-only target motion analysis. IEEE Trans. Aerosp. Electron. Syst. AES-17:162-166.
- Petridis, V. 1981. A method for bearings-only velocity and position estimation. IEEE Trans. Automat. Contr. AC-26:488-493.
- Sexton, S.N., R.S. Holt and A. Jackson. 1989. Report of a marine mammal survey of eastern tropical Pacific aboard the research vessel McArthur July 28 - December 6, 1988. NOAA-TM-NMFS-SWFC-128. 125 pp.
- Wade, P.R. and T. Gerrodette. 1992. Estimates of dolphin abundance in the eastern tropical Pacific: Preliminary analysis of five years of data. Rep. Int. Whal. Commn. 42:(in press).

Figure 1. Difference between CAST and observer angles for data collected in 1987.

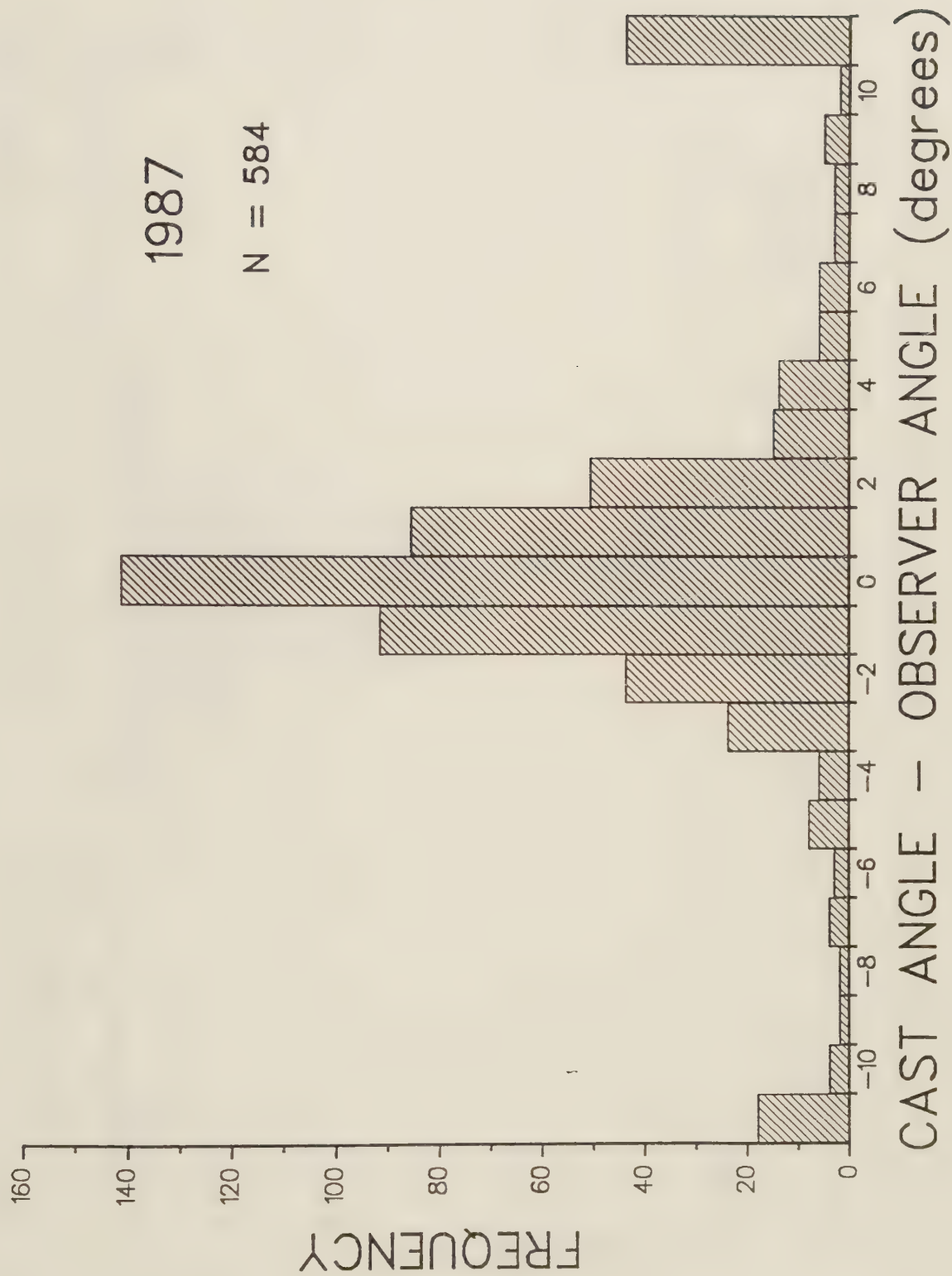


Figure 2. Difference between CAST and observer angles for data collected in 1988.

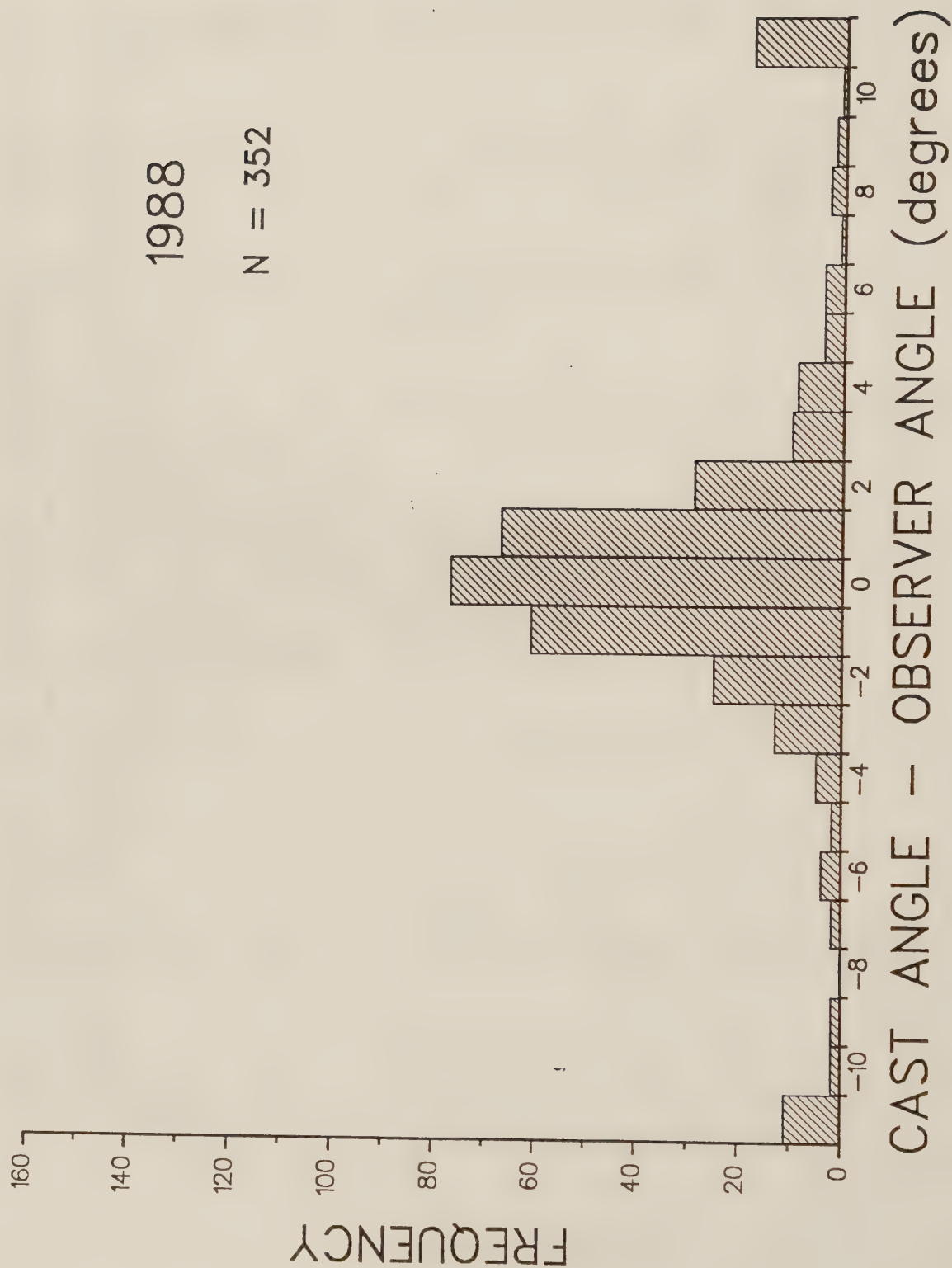


Figure 3. Difference between CAST and observer angles for data collected in 1989.

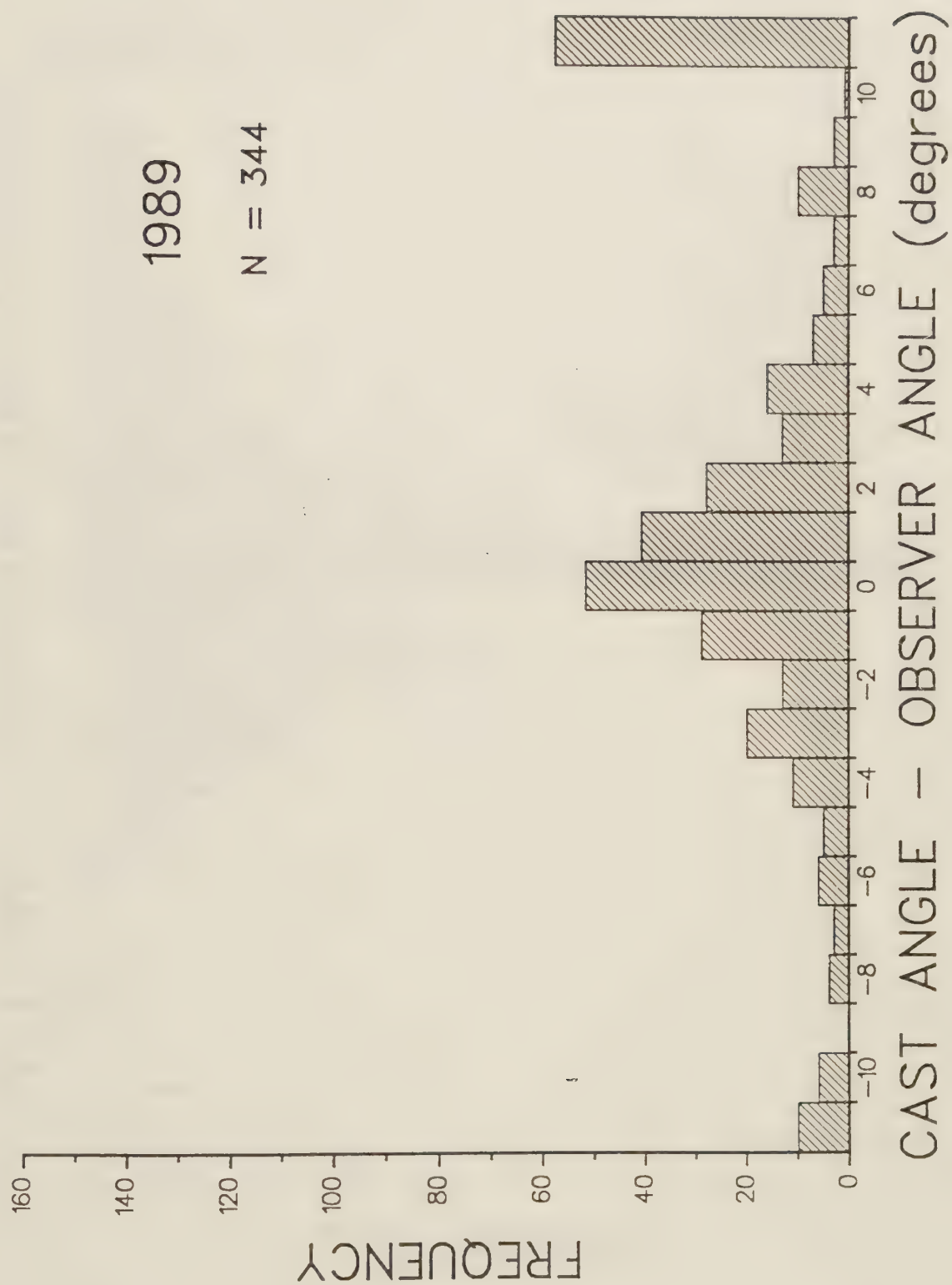


Figure 4. Difference between the time of the CAST tracking sequence and the time of the sighting (1987 data).

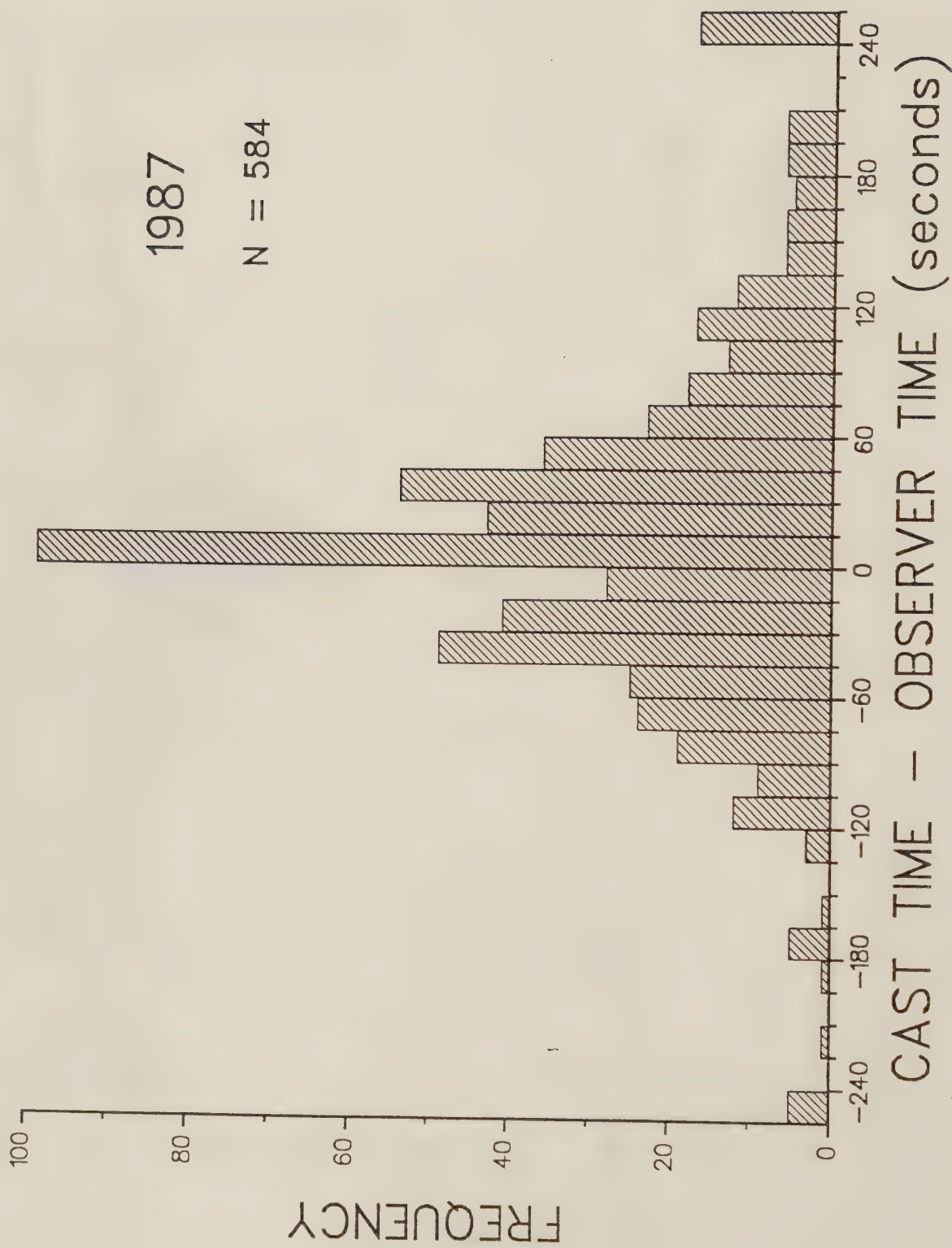


Figure 5. Difference between the time of the CAST tracking sequence and the time of the sighting (1988 data).

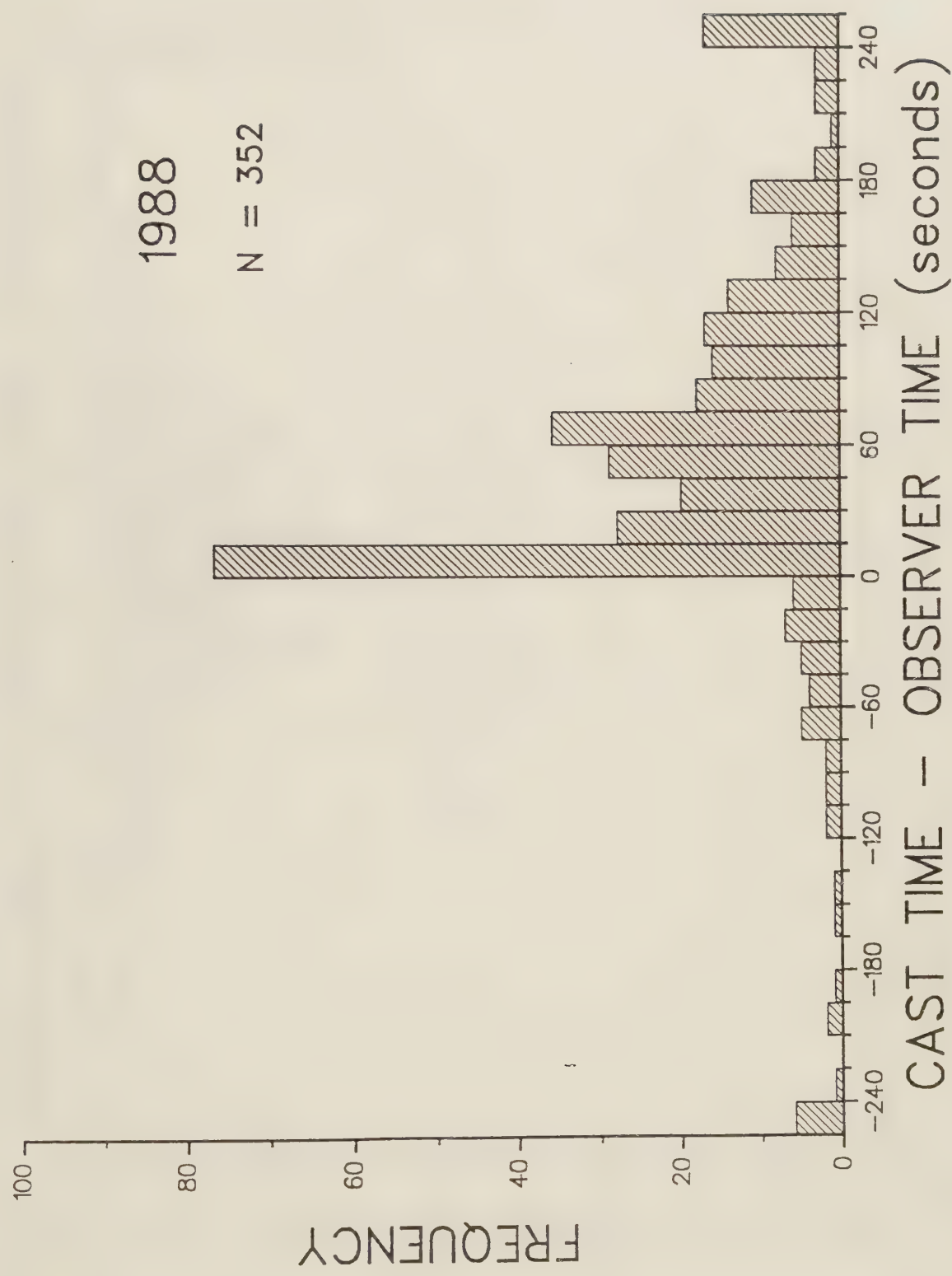


Figure 6. Difference between the time of the CAST tracking sequence and the time of the sighting (1989 data).

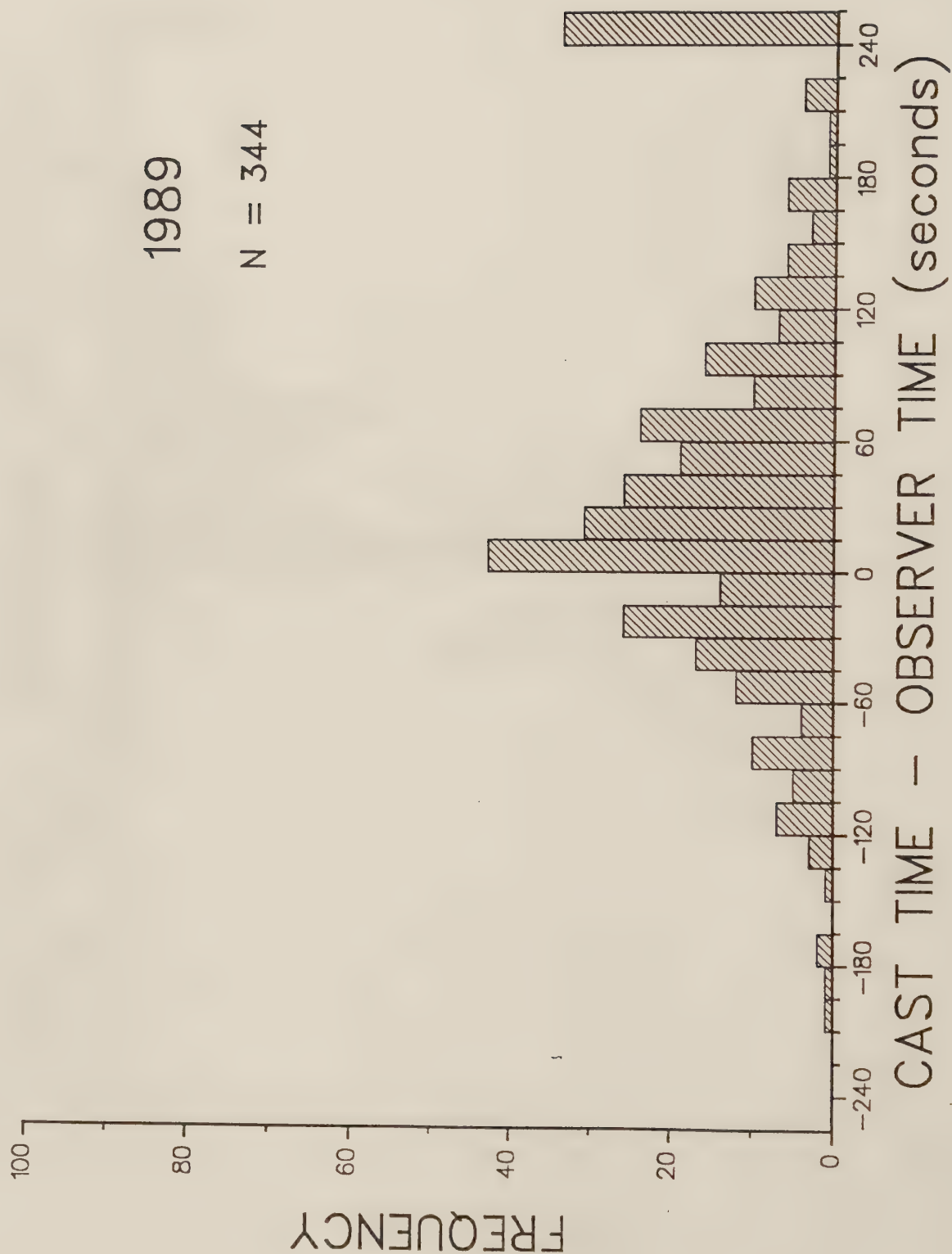


Figure 7. Scatterplot of time difference versus angle difference for data collected in 1987.

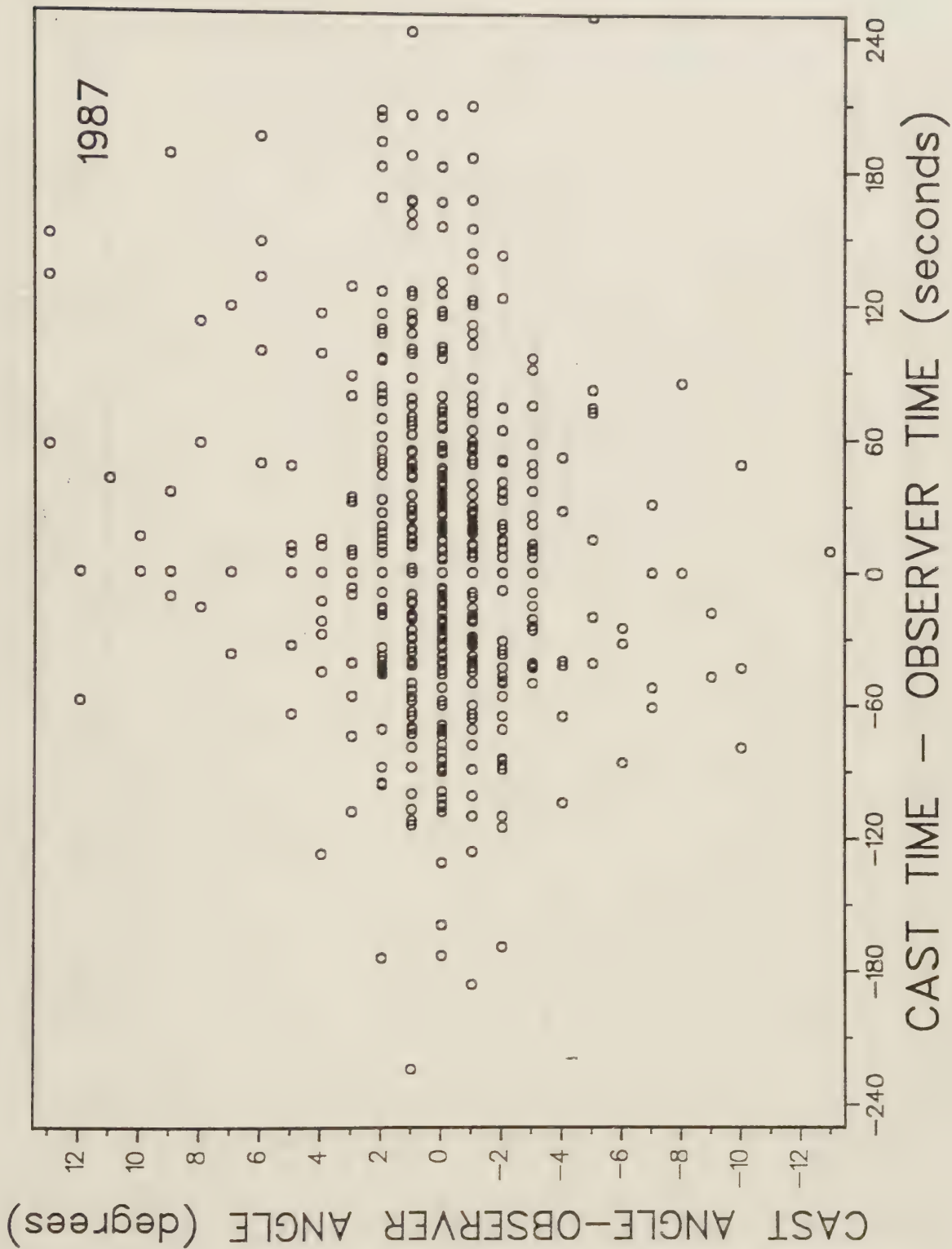


Figure 8. Scatterplot of time difference versus angle difference for data collected in 1988.

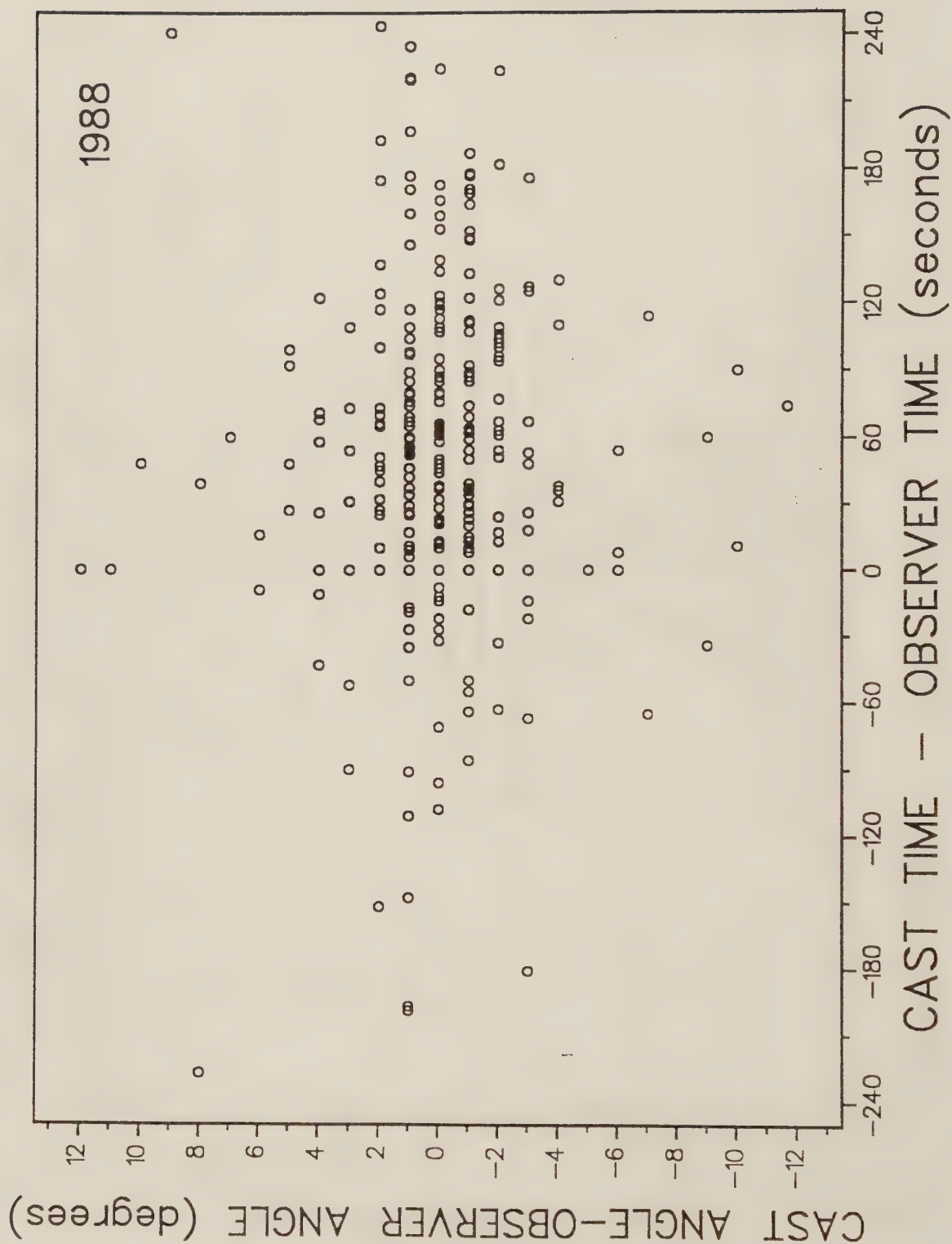


Figure 9. Scatterplot of time difference versus angle difference for data collected in 1989.

